71th International Astronautical Congress (IAC) – The CyberSpace Edition, 12-14 October 2020.

IAC-20.B6.1.x58461

A proposal an innovative Framework for the Conception of the Ground Segment of Space Systems.

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Abstract

An increasing number of space missions - which include the classes of Scientific, Earth Observation, Geostationary, and Educational - drives the search for solutions lined up between space and the ground segments. Space agencies, such as: CNES, DLR, ESA, ESOC, INPE, JAXA and NASA, stimulate initiatives and the development of projects aimed at efficiency and cost reduction of missions. The classes of satellites and spacecraft have requirements that, classically, determine the design and development of the mission; these requirements currently cover definitions, such as communication protocols, uplink and downlink rates, onboard processing and remote reconfiguration of service and payload modules, and direct new modes (models) of controlling and operations that are requested from the ground segment. Among the activities for designing systemic solutions to attend a space mission, the ground segment has a significant number of questions to be answered in order to meet cost and operability requirements and reach a successful mission. From the perspective of the ground segment, it is essential to demonstrate the innovation of concepts that are required of systems due to the increase in volume and kind of data (Big Data), and their processes, for example, machine learning and artificial intelligence; and also of the utilization of communication protocols, and onboard processing. These concepts include the development of projects and the operation of missions and must be implemented according to the guidelines of the European Cooperation for Space Standardization (ECSS) and National Aeronautics and Space Administration (NASA), in the area of systems engineering, as well as meeting the recommendations of the Consultative Committee for Space Data Systems (CCSDS), such as: Management Services for Data Transfer, Space Link Extension (SLE) Protocol Services for Cross Support and Interoperability. This paper presents a proposal an innovative Framework for Conception of the Ground Segment of Space Systems that allows supporting to the design of space systems solutions, in the perspective of the Ground Segment, improving and standardizing the procedures to systems engineering, establishing methodologies for the optimization of development, management, and implementation of the Ground Segment projects and their interaction with the Space Segment. The proposed Framework will allow the proposition, the conception and the specification of requirements for the ground segment that should collaborate to define requirements for the architecture of space systems and to ensure the fulfillment of mission objectives with efficiency and cost reduction. The possible contributions of the framework and suggestions for future works are also presented in the paper.

Keywords: CCSDS, MBSE, Expert Systems, Ground Segment, Space Mission, Interoperability.

Acronyms

ALC Alcântara (Brazilian TT&C Ground Station)
CAST China Academy of Space Technology
CBA Cuiabá (Brazilian TT&C Ground Station)
CBERS China-Brazil Earth Resources Satellite
CCSDS Consultative Committee for Space Data Systems
CDSR Remote Sensing Data Center
CFDP CCSDS File Delivery Protocol
CLTU Communications Link Transmission Unit
CMCD Mission Center
CNES Centre National d'Études Spatiales
DLR Deutsches Zentrum für Luft- und Raumfahrt e.V (German Space Agency)
ECSS European Cooperation for Space Standardization
EIA Electronics Industry Association
ESA European Space Agency
ESOC European Space Operations Centre
ESTRACK ESA Tracking Network
IEC International Electrotechnical Commission
INCOSE International Council on Systems Engineering
INPE National Institute for Space Research

ISO	International Standards Organization
JAXA	Japan Aerospace eXploration Agency
LEOP	Launch and Early Orbit Phase
MBSE	Model-Based Systems Engineering
NASA	National Aeronautics and Space Administration
RAF	Return All Frames
RCF	Return Channel Frames
SATCS	SATellite Control System
SCC	Satellite Control Centre
SLE	Space Link Extension
SysML	Systems Modeling Language
TC	Telecommand
TM	Telemetry
TSL C	Taiyuan Satellite Launch Base
TT&C	Telemetry, Tracking and Command

1. Introduction

The new space missions that can comprise of the satellites' scientific, earth observation, geostationary, and educational drive the search for solutions lined up between space and the ground segments. This scenario stimulates initiatives and the development aimed at efficiency, the interoperability, the cross support, and cost reduction of missions.

Classes of satellites and spacecraft have requirements that, classically, determine the design and mission development, and direct new modes (models) of controlling and operations that are requested from the ground segment.

From the perspective of the ground segment, it is essential to demonstrate the innovation of concepts that are required of systems due to the increase in volume and kind of data, and their processes, for instance, machine learning, artificial intelligence, communication protocols, and onboard processing.

These concepts include the projects development and the missions operation, and must be implemented according to the guidelines of the European Cooperation for Space Standardization (ECSS) and National Aeronautics and Space Administration (NASA), in the area of systems engineering, notwithstanding not limited to these major entities.

In additional to ECSS and NASA, the concepts meet the recommendations of the Consultative Committee for Space Data Systems (CCSDS), such as Management Services for Data Transfer, Space Link Extension (SLE) Protocol Services for Cross Support and Interoperability.

This paper presents a proposal an innovative Framework for Conception of the Ground Segment of Space Systems that allows supporting to the design of space systems solutions, in the perspective of the Ground Segment, improving and standardizing the procedures to systems engineering, establishing methodologies for the optimization of development, management, and implementation of the Ground Segment projects and their interaction with the Space Segment. It is based on an examination of the literature [1] to determine the possible contributions of this proposal to the development of space systems.

The paper is structured as follows: section 2 presents the Space Mission Elements, Ground Segment Architecture, and Ground Station Network; section 3 presents an overview about engineering technologies. The section 4 presents a proposal an innovative Framework for the Conception of the Ground Segment of Space Systems and finally section 5 the conclusions.

2. Space Missions Elements

Normally, a space mission is composed of the following segments: Launch, Space, Application and Ground.

Figure 1 shows the elements of the CBERS-4A mission [2]. The CBERS program is a partnership agreement involves the National Institute for Space Research (INPE) and China Academy of Space Technology (CAST).

A Launch Segment is responsible for placing the satellite in orbit. The CBERS-4A was launched in 2019 from Taiyuan Satellite Launch Base (TSL C) far 700 km of Beijing (China), through the launch vehicle Long-March 4B.

According to ECSS [3], [4] and NASA [5], the Space Segment is composed, generally, of the spacecraft configured with the service module and scientific instruments payload following the recommendations CCSDS [6], [7], [8], and as discussed in Fortescue et al. [9] and Larson and Wertz [10].

The Application Segment at INPE is comprised by Reception and Recording Station and by the Mission Center (CMCD) to plan and coordinate the operations imaging acquisitions of the satellite, also comprising the Remote Sensing Data Center (CDSR, acronym in Portuguese) which processes and stores the images, and makes them available to the users.

Finally, a Ground Control Segment (or simply Ground Segment) is responsible for controlling the satellite, monitoring, and analysing its on-orbit operation is relying on the use of the Telemetry, Tracking, and Command (TT&C) Ground Stations and Satellite Control Centre (SCC). The ground control segment projects, basically, follow guidelines ECSS [3] and NASA [5] for systems engineering and the CCSDS recommendations for interoperability and cross support [7] and [8].

The TT&C Ground Stations are in charge of establishing communication between the ground segment and the satellites monitored, and the SCC is responsible for the plan and executes all activities related to the satellite's control.

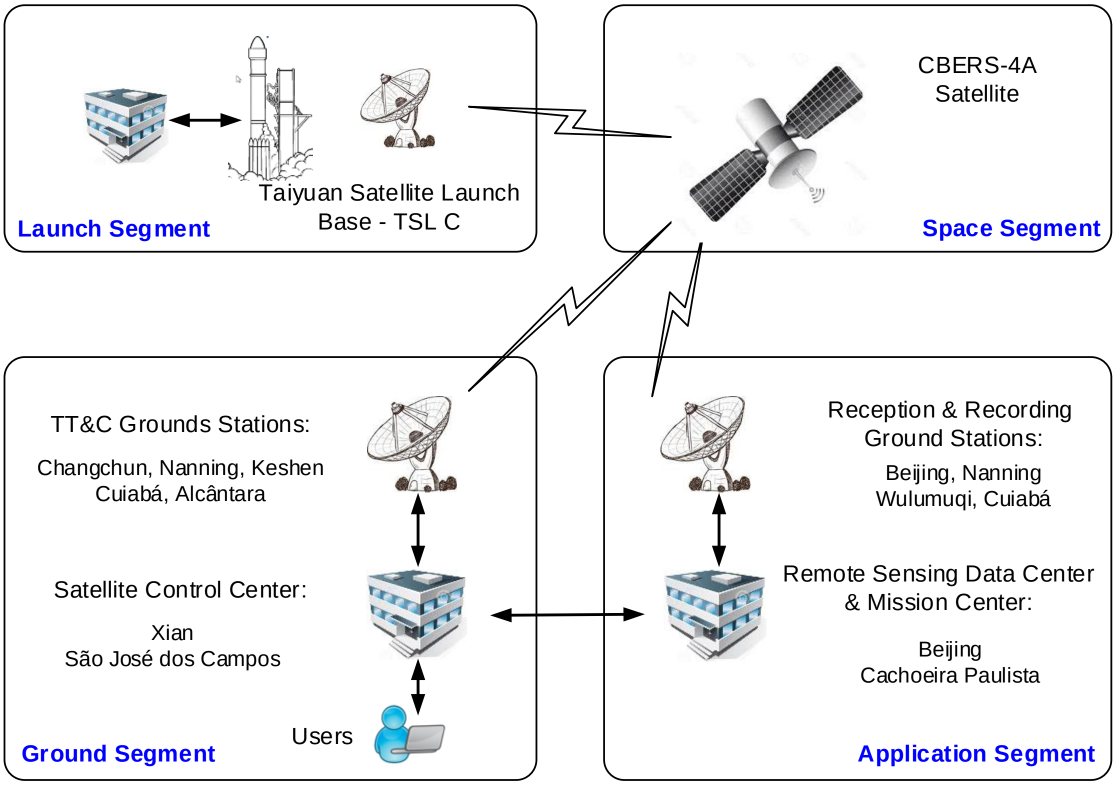

Figure 1. System Elements Overview, adapted from [2].

2.1. Ground Segment: A Brief history of the architectures

Different architectures were proposed to interoperability and cross support until 2002, initially receiving Telemetry (TM) and sending Telecommand (TC). These architectures included the installation of specific hardware and the implementation of bilateral interfaces based on software.

According to Schulz et al. [11], a solution was the installation of hardware at the provider ground stations, a simple approach, notwithstanding, with great effort for transportation, maintenance, operational training, and removal after supporting the Launch and Early Orbit Phase (LEOP).

Another technique to fix these issues was the use of bilateral interfaces without installing hardware systems. The space agencies defined an interface, a protocol and the data coding. This technique required the development of gateways with high cost, and effort for analysis, testing, and acceptance of the interfaces to attend a specific mission.

In order to resolve the problems associated with the considerable number of interfaces for the exchange of services between the providers (ground stations) and users (satellite control centres), the CCSDS, in joint work with space agencies, recommends a set of standardized services for Telemetry and Telecommand. This set of services is called Space Link Extension (SLE) Protocol Services [7], [12], [13], [14], and [15] and their management activities.

According to Barkley et al. [16] and Pietras et al. [17], the standardization of SLE service management activities is presented in the recommendations CCSDS [18] and [19]. These SLE Protocol Services recommendations were adopted by many space agencies (non-exhaustive list), such as CNES, DLR, ESA, ESOC, INPE, JAXA, and NASA, and by private sector companies.

2.1.1. Ground Segment Architecture

Due to the adoption of SLE Protocol Services there are, currently, space agencies networks and also private companies networks. These two network types meet interoperability and cross support requirements.

Figure 2 illustrates an architecture of the ground segment proposed by Julio Filho [20] to be implemented at INPE. The proposal aims to simplify access to ground stations and allow real-time detection of redundancy between two stations; transparency in switching and, as consequence, a greater ability to tracking the spacecraft, and meeting interoperability and cross support requirements.

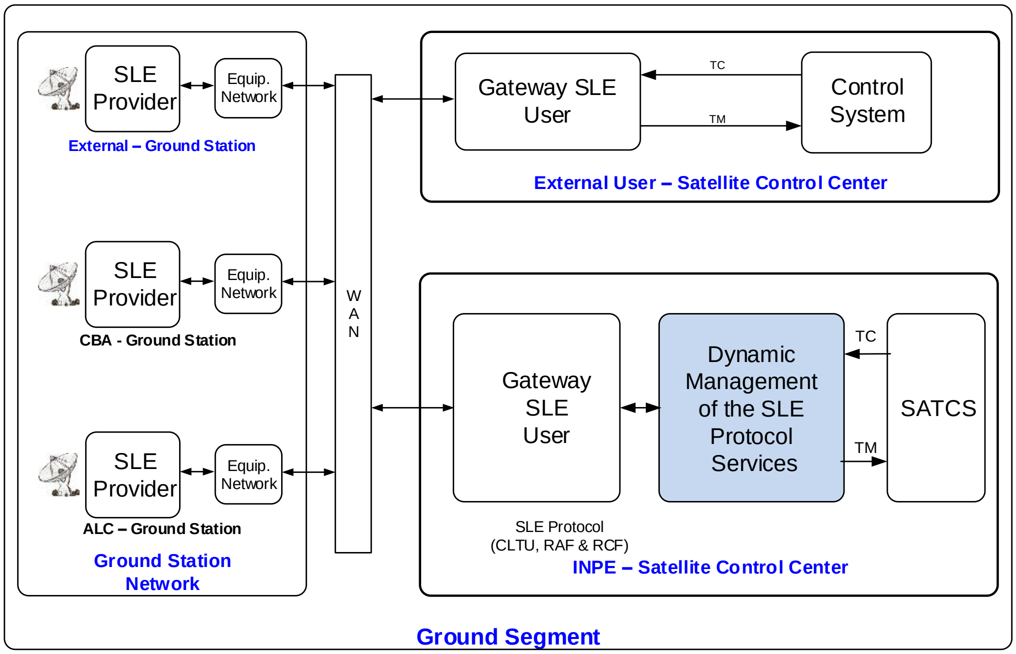

Figure 2. Architecture of the ground segment, adapted from [20].

2.1.2. Ground Station Network

A Ground Station Network system benefits the interoperability and cross support. An example is ESA's ESA Tracking Network (Estrack) that provides the link between spacecraft and ESOC according to ESA [21]. Figure 3 shows SLE Service Providers and Users.

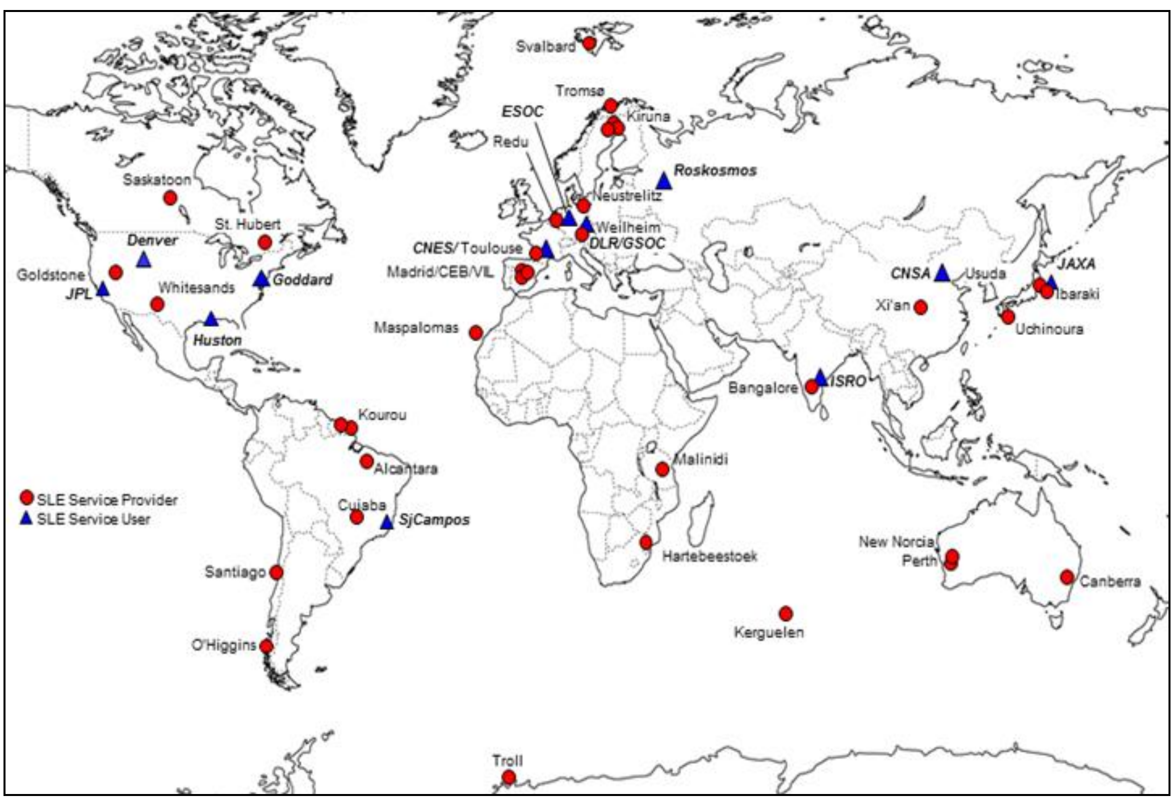

Figure 3. SLE Service Providers and Users.

3. *Technologies*

This section presents an overview of technologies that are available to be used for the development of systems, such as Space Systems Engineering and Systems Engineering, Model-Based Systems Engineering, and Expert Systems.

3.1. *Space Systems Engineering and Systems Engineering*

According to Macdonald [22], the ECSS, established in 1993, to develop a coherent set of standards for use in all European space activities, for example ESA projects. This European initiative has gained global importance and it provides an excellent resource for the development of good practice.

The ECSS documentation architecture approach three branches: 'Management', 'Product Assurance' and 'Engineering', each of which contains a subset of standard documents split into four hierarchical levels, defined to the detail level of detail required to differentiate major functions, disciplines, and activities.

According as Macdonald [22], ESA and NASA continue leading the development of space systems engineering practices through documented practices, training and standards.

On the other hand, the broader field of systems engineering is being developed by organizations such as the Electronics Industry Association (EIA), the International Systems Engineering Council (INCOSE), the International Standards Organization (ISO) and the International Electrotechnical Commission (IEC).

3.2. *Model-Based Systems Engineering*

The systems continue to increase in complexity and more stringent and standardized practices are needed [23]. Model-Based Systems Engineering (MBSE) collaborates to manage complexity by moving the practice of document-based systems engineering to a model-based approach.

This approach improves communications between development teams, the quality of specifications and design, and enables the reuse of specifications and artifacts [24].

According to INCOSE [25], MBSE is the formal application of modeling to support the requirements of systems, design, analysis, verification and validation of activities initiated in the conceptual design phase and continuing throughout the development of the later stages of the life cycle.

MBSE approach defines formal semantics for technical information and allows constructing patterns defining element relationships and facilitating auditing and completeness checking, and it ensures consistency across all generated products through single-source-of-truth [26].

Figure 4 illustrates the MBSE approach. Firstly, Stakeholders, Concerns and Concepts; secondly, Elements, Functions, Behaviors, and Requirements; thirdly, Components, Interfaces, Resource and Metrics.

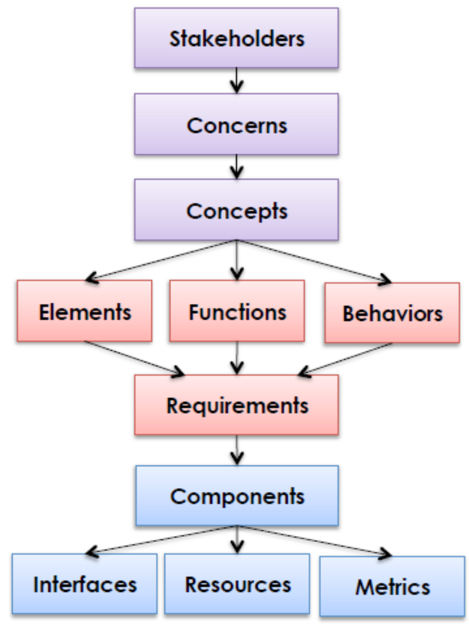

Figure 4. MBSE approach [26].

A widely used modeling language is Systems Modeling Language (SysML) [24]. It is a semantic-based graphical modeling language to represent requirements, behavior, structure and properties of systems and their components, and aims to model systems such as automotive, medical, aerospace, etc..

3.3. *Expert Systems*

Expert systems store and process knowledge acquired from experts in an area of knowledge and are able to make decisions, infer conclusions, from knowledge base as illustrated in Figure 5 [27].

Additionally, it must be able to learn new knowledge to improve their reasoning performance and the quality of their decisions.

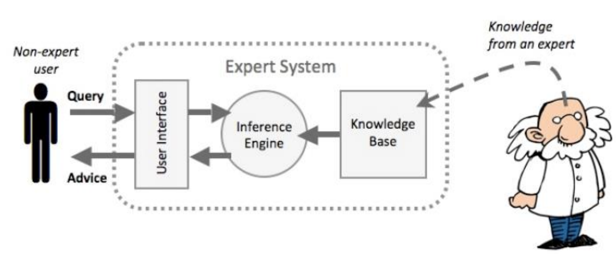

Figure 5. Expert System Diagram [27].

An expert system consists of two subsystems: a) the knowledge base that represents the facts and rules, and (b) the inference mechanism that has the responsibility to apply the rules to known facts to deduce new facts.

The idea is to apply an expert system - including processes that it using machine learning and artificial intelligence - to compose the proposed framework and collaborate to make decisions and indicate possible solutions for the implementation of the projects.

4. A proposal an innovative Framework for Conception of the Ground Segment of Space Systems

Space agencies encourage initiatives and the missions' development aligned between the space segment and the ground segment, which aim at efficiency, interoperability, cross support, and reduction risks and costs.

From the perspective of the ground segment, it is essential to demonstrate the innovation of concepts that are required of systems due to the increase in volume and kind of data, and their processes, for example, Machine Learning and Artificial Intelligence (expert systems). It important considers, also, the utilization of communication protocols - such as the SLE and the protocol for transporting files CCSDS File Delivery Protocol (CFDP) [8] and [28], onboard processing, and the high data rate for uplink and downlink links.

In this scenario, the systems become more complex and the legacy of successful project development must be accompanied by mechanisms that enable collaborations among stakeholders and ensure the fulfillment of mission objectives.

The review literature directs the studies towards the elaboration of the proposal for a framework based on MBSE and Expert Systems for the design of the ground segment of space systems.

This proposed framework should contribute to research aimed at increasing the efficiency of the ground segment in reception, control, storage, distribution, and access by multiple users.

The framework should allow the proposition, design, and specification of ground segment requirements that can collaborate to define or refine the space systems architecture requirements.

Figure 6 presents an elements overview of the proposed framework: firstly, Space and Ground Segments, Guidelines, Agencies; secondly, Expert Systems, Systems Models, Management; thirdly the database.

In this framework, the mission requirements initially guide the space segment development and define the ground segment requirements. These requirement sets should allow the modeling, simulation and assessment of behavior and if necessary, be evaluated by expert systems to make decisions and indicate in advance possible solutions for the project implementation.

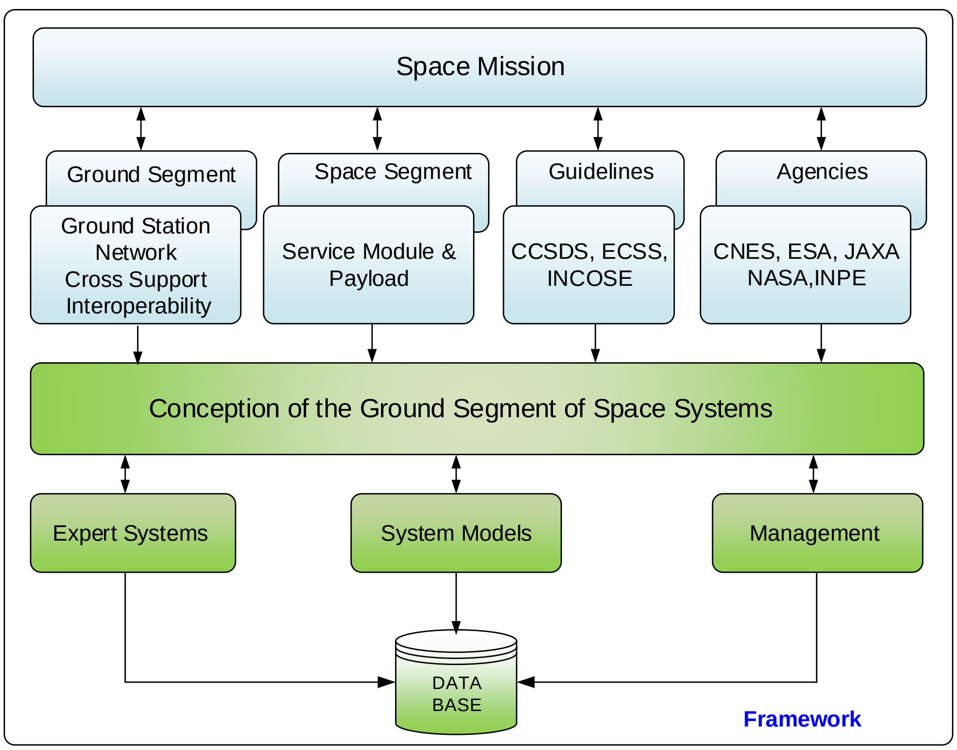

Figure 6. Elements overview of the proposed Framework.

Figure 7 shows a dynamic view of the framework. First, it is necessary to elicit the requirements of the space segment and concurrently with the ground segment requirements; second, we have to create and validate the models, and the simulations. The result can be positive or negative, when the negative result is obtained the expert system can indicate in advance a possible solutions. Finally, the database should be updated.

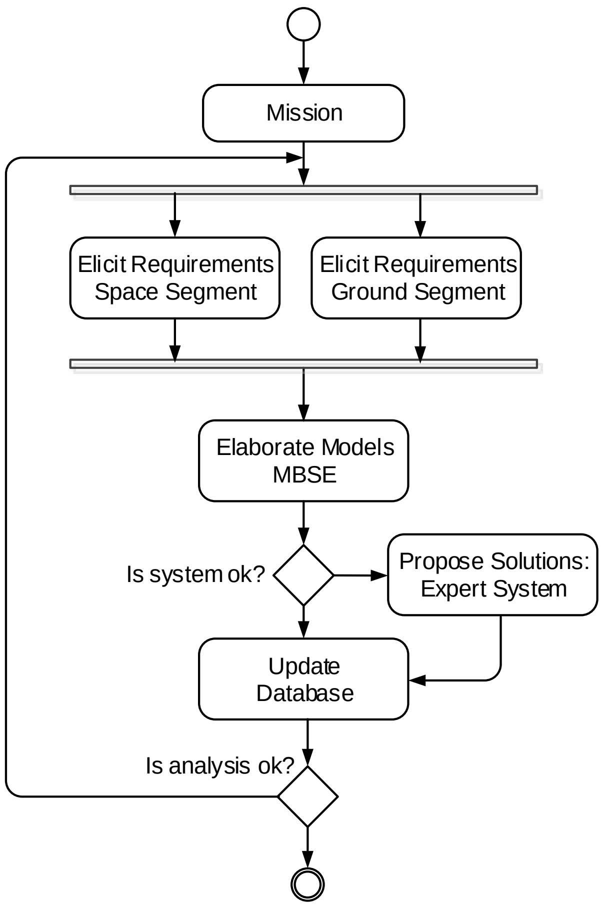

Figure 7. Dynamic View of Framework.

4.1. Application Example

As a scenario, we can consider that on design phase of the spacecraft, the requirement for an x-band imaging camera based on the volume of data captured and stored onboard. In this case, the hypothetical data rate is 900 Mbps.

Does the ground segment, existing or under development, meet the requirement: reduced data storage onboard?

What are the impacts on the ground segment related to operating scenarios, processes, and interfaces?

Is there an increase in the number of passes through the ground station?

According to Smith et al. [23] changes in the design of the spacecraft typically generate additional requirements and costs for the ground segment and impacts can be more difficult to assess without complex analyzes.

In this example, the models can collaborate to assess the real impacts, in the ground segment, of the proposed changes in the space segment and anticipate the presentation of new solutions. Modeling and analysis at the beginning of the development cycle can reduce the need for project review, the assessment of alternative solutions, costs, and risks at the end of development.

5. Conclusions

The results of this first approach direct our efforts towards the design of solutions for space systems, from the perspective of the ground segment, according to the principles of Model-Based Systems Engineering and the collaboration of Expert Systems, in order to demonstrate its possible advantages (communication, quality, productivity and risk reduction) and possible disadvantages.

As with other complex systems (automotive and medical), the models can collaborate to assess the real impacts of proposed changes, and anticipate the presentation of solutions at the beginning of the development and continue throughout the later phases of the systems life cycle.

The next steps of work include ontology studies, models definition, and the gradual implementation of these models, simulations and, analyses with the elaboration and incorporation of expert systems as part of the framework.

Acknowledgements

We thank the Brazilian National Institute for Space Research (INPE, acronym in Portuguese) by their support.

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Biography

Antonio Cassiano Julio Filho is graduated at Analysis and Development of Systems from Faetec, Brazil and Master's (2015) at Space Engineering and Technology from Brazilian National Institute for Space Research (INPE) and is a PhD. Student in Space Engineering and Technology.

He has 35 years of the work at INPE in the Space Engineering and Technology in the area Ground Systems Development Division in the design, development and integration of the ground segment for the tracking and control of satellite.

Mr. Julio Filho is INPE Observer Member to the Cross Support Transfer Services Working Group of the CCSDS and Member of the Commission of Study CE:08.010.70/ABNT, to the review and the development of Space Data and Information Transfer Standards, derived from CCSDS Recommendations.

Maurício Gonçalves Vieira Ferreira is a researcher at the Satellite Control Centre at INPE. Graduated in Data processing Technology - Faculdade de Administração e Informática (1987), degree in business administration from the Faculdade Maria Augusta (1993), master in Applied Computing for the National Institute for Space Research (1996) and PhD in Applied Computing for the National Institute for Space Research (2001).

He is Professor in the postgraduate course of INPE in Space Engineering and Technology (ETE): the area of concentration and Space Systems Management Engineering. Member of the International Committee for Standardization of software in space area (CCSDS).

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She works at INPE since 1985. She has been involved in the following space missions: French-Brazilian Microsatellite (FBM) and China-Brazil Earth Resources Satellites (CBERS). Since 2008 acts as teacher in the Space Engineering and Technology pos-graduation Program at INPE, from 2012 to 2014 acted as Head of Space Systems Management and Technology area of the post-graduation of the Space Technology and Engineering Course. Her areas of research are: satellite verification and validation techniques and methods, model-based approaches for space applications, automatic test generation from state models and satellite simulation.